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Photovoltaics and renewable energies in Europe

Arnulf Jäger-Waldau*,[1]

European Commission, Joint Research Centre, Renewable Energies Unit, Via E. Fermi 1, TP 450, Ispra (VA) I-21020, Italy

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Abstract

Photovoltaics and renewable energies are growing at a much faster pace than the rest of the economy in Europe and worldwide. This and the dramatic oil price increases in 2005 have led to a remarkable re-evaluation of the renewable energy sector by politics and financing institutions. Despite the fact that there are still discrepancies between the European Union and the USA, as to how to deal with climate change, renewable energies will play an important role for the implementation of the Kyoto Protocol and the worldwide introduction of tradable Green Certificates. Apart from the electricity sector, renewable energy sources for the generation of heat and the use of environment friendly biofuels for the transport sector will become more and more important in the future.

Keywords: Renewable energies; Biomass; Wind energy; Photovoltaic; Energy challenge; Policy options; Technological development; Market development; Kyoto Protocol

Contents

*Tel.: +39 0332 789119; fax: +39 0332 789268.
E-mail address: arnulf.jaeger-waldau@cec.eu.int.
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1. Energy challenges and options

The increase of the energy consumption of 10% from 1990 to 2000 [1] in the European Union has led to an increase of energy imports because the community's own production is insufficient for the Union's energy requirements. As a result, external dependence for energy is constantly increasing, and is presently about 49%. With the enlargement of the European Union to 25 Member States in 2004, it is expected that this dependency will increase to over 80% in 2020 if no countermeasures are taken.

Besides the increasing pressure on the supply side of energy by the increasing world energy demand, environmental concerns are nowadays shared by a majority of the public and add to the list of weaknesses of fossil fuels and the problems of nuclear energy. These concerns include the societal damage caused by the energy current supply system, whether such damage is of accidental origin (oil slicks, nuclear accidents, methane leaks) or connected to emissions of pollutants.

What are the energy challenges we are facing?

- *Sustainability*: De-coupling of economic growth from depletion of resources and global warming,
- *Security of supply*: Ensuring long-term availability of energy sources,
- *Safety of the energy chain*: Accidents, political stability, import dependence,
- *Growing demand in developing countries*: About 2000 million people have no basic electricity service. An electricity distribution grid outside of large cities will never be economically viable.

How can we face these challenges?

The answer to this question leaves us with few options to decrease the energy intensity and, as this is not enough, to increase the Union's indigenous energy supply.

- *Decrease energy intensity (Mtoe/GNP)*
  (i) Increase efficiency of energy end-use (domestic, industry, transport).
  (ii) Increase efficiency of electricity generation.
- *Increase (indigenous)] supply*
  (i) New and renewable energies.
  (ii) Examine nuclear option.

Decrease of energy intensity alone will not solve the problem, as our energy consumption structure, mainly of electricity and for transport, is a consequence of our

lifestyle and the population on this planet. The IEA predicts an increase of the world population to 10 billion people in 2050. In 2002 the worldwide primary energy supply corresponded to 13.6 TW power continuous in use. For 2050 the energy demand is expected to increase to 33.2 TW power continuous in use. If 50% of this increase would be in electricity, this would require 10,000 power plants with 1 GW, every second day a new one.

Furthermore, the public of industrialised countries is split over the issue of nuclear energy use. Therefore, the future of nuclear energy is uncertain, particularly in Europe. It depends on several factors, including: a solution to the problems of managing and stocking nuclear waste; the economic viability of the new generation of power stations; the safety of reactors in eastern Europe, in particular applicant countries; and the global fight against nuclear proliferation.

Renewable energies do not face these safety and security concerns and there is an abundant supply within the European Union. However, regardless of the type of renewable energy source, there are obstacles of a structural nature to their implementation. The current economic and social system is based on centralised conventional sources of energy (coal, oil, natural gas and nuclear energy) and their distribution system. The second main barrier is of financial nature. Renewables need significant initial investment, as was the case for the other energy sources, such as coal, oil and nuclear energy. We should not forget that most of these investments were either made by public companies or secured by public credit guarantees.

Therefore, the renewable energy market in the European Union cannot be expected to develop regularly without a support policy in the medium term on the part of the public authorities. Support measures stretch from direct subsidies in favour of renewable energy sources or the obligation on the part of electricity producers and utilities to purchase a minimum percentage of electricity produced from renewable sources of energy through to aid research or financing mechanisms (interest subsidies, guarantee funds, parafiscal tax on other sources of energy).

2. The political frame in the European Union

In December 1997, the European Council and the European Parliament adopted the "White Paper for a Community Strategy and Action Plan" [2]. In this paper the aims were described as follows: "Renewable energy sources may help to reduce dependence on imports and increase security of supply. Positive effects are also anticipated in terms of CO_2 emissions and job creation. Renewable energy sources accounted 1996 for 6% of the Union's overall gross internal energy consumption. The Union's aim is to double this figure by 2010".

About 3 yr later the Green Paper "Towards a European strategy for the security of energy supply" [3] was published. The Green Paper highlighted the energy supply dependence of the European Union (50% imported now, with Candidate Countries 80%) and that if no measures are taken this dependence will rise in the next 20–30 yr to 70% of the Union's energy requirements, as opposed to the current 50%. The enlargement in 2004 will aggravate this trend. Therefore, the European Union's long-term strategy for energy supply and security must be designed to ensure the well-being of its citizen, while respecting environmental concerns and looking towards sustainable development [4].

The target of the White Paper to double the share of renewable energies from 6% in 1995 to 12% in 2010 as well as the Kyoto Protocol commitment to reduce the greenhouse gas emissions by 8% are once more pointed out. The Green Paper also states that at the moment it seems unlikely that nuclear energy will see renewed growth. This is due to the liberalisation of the energy markets and its competitive position compared with other energy sources (e.g. natural gas), public acceptance and a possible solution to the problem of nuclear waste. At the present political situation (decision by certain Member States to relinquish this sector), it is likely that the contribution of nuclear energy will change little from now until 2020.

The increasing demand for energy of the transport sector (+50% until 2010) and its 98% dependence on oil creates a further demand for renewable energies, e.g. biofuels). This is of particular importance as the European Union is already 76% (EU15) dependent on oil imports and it is likely to rise to 94% (EU30) in 2010 if business as usual is pursued.

Last but not least the role of the European Union as a player in the world energy market is an argument to promote renewable energies. As the EU relies on imported energy, the dependence on supply and demand conditions in the international market have to be taken into account. Therefore, the forecasted rise by some 65% over 20 yr, from 9.3 billion toe in 2000 to 15.4 billion toe in 2020, due to the world's population growth and the growing demand of developing countries, will have a substantial impact on international fossil fuel prices. International efforts to promote renewable energy and energy efficiency are necessary to reduce this trend.

The main instruments to promote the use of renewable energies at the moment are as follows.

2.1. Directive on the promotion of electricity produced from renewable energy sources in the internal electricity market (Directive 2001/77/EC) [5]

Main aspects of the Directive: An indicative target for the share of RES-E was set for each Member State (Figs. 1 and 2), but the countries have the freedom at least until 2005 to choose the kind of support schemes (measures and incentives) with which they want to reach the targets. The Member States were originally obliged to report about the progress of implementation and the success of the chosen methods every 2 yr. On 27 October 2005, the Commission has to present a report on experience gained with the application and co-existence of the different mechanisms. If deemed necessary, the report should be accompanied by a proposal for a Community framework with regard to support schemes for electricity produced from renewable energy sources to ensure that the targets for 2010 are met. The Directive also regulates the grid access and obliges the Member States to ensure a non-discriminating treatment of electricity generated by renewable energies.

The RES-E Directive was groundbreaking, as the strategy of developing renewables was for the first time cast into a legislation instrument. Though still operating with indicative targets for the electricity production from RES, it strengthened the development with the following principles:

- Quantified national targets for consumption of electricity from renewable sources of energy, i.e. establishment of RE *(here specifically RES-E) ramp up as a common goal in the EU. No "escape" from the targets, except some mitigation, if a country introduces*

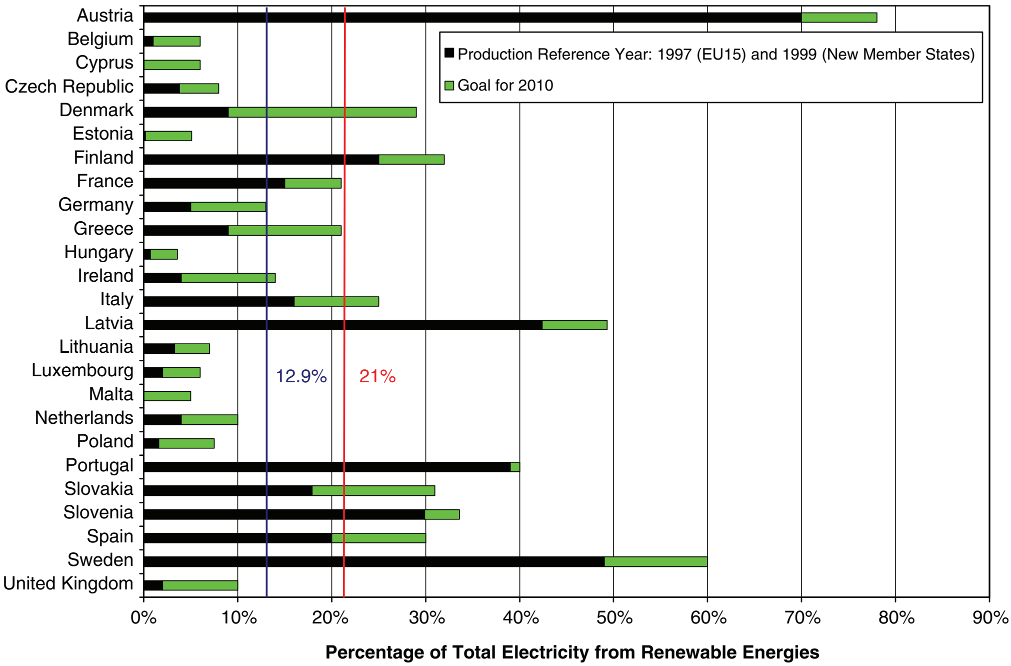


Fig. 1. Indicative Renewable Energy Targets set in the Directive for the different Member States. The blue line is 1995 (12%) and the green line 2010 (22%).

very successfully Energy-End-Use efficiency measures, which then would lower the denominator for the RE-percentage to achieve.

- Acceptance of the different national support schemes and putting them under these quantitative target benchmarks, *i.e. letting a certain competition of support schemes happen, as long as they lead towards the goal.*
- Announcement of issuing a harmonised support scheme to be suggested by the Commission in case of necessity revealed by regular monitoring, *i.e. threatening enforcement of more efficient (and different) schemes if existing methodologies would turn out to be insufficient.*
- Simplification of national administrative procedures for authorisation, *i.e. addressing obstacles under national authorities, thus underlining the importance of the common goal.*
- Guaranteed access to transmission and distribution of electricity from renewable energy sources, *i.e. enforcing a pro-RE behaviour of the established energy market participants, which in fact contributed ground to pro-RE jurisdiction.*

In fact all 15 Member States have adopted national targets in line with the reference values listed in Annex I of the Directive; also the 10 New Member States have set up national targets in their Accession Treaties in April 2003. Consequently, these national targets are, on the whole, also sufficiently ambitious to achieve the EU-25 target of a 21% RES-E share by 2010.

The target for the cumulative photovoltaic systems capacity installed in the European Union by 2010 is 3000 MW or a 100-fold increase of the capacity in 1995. Electricity

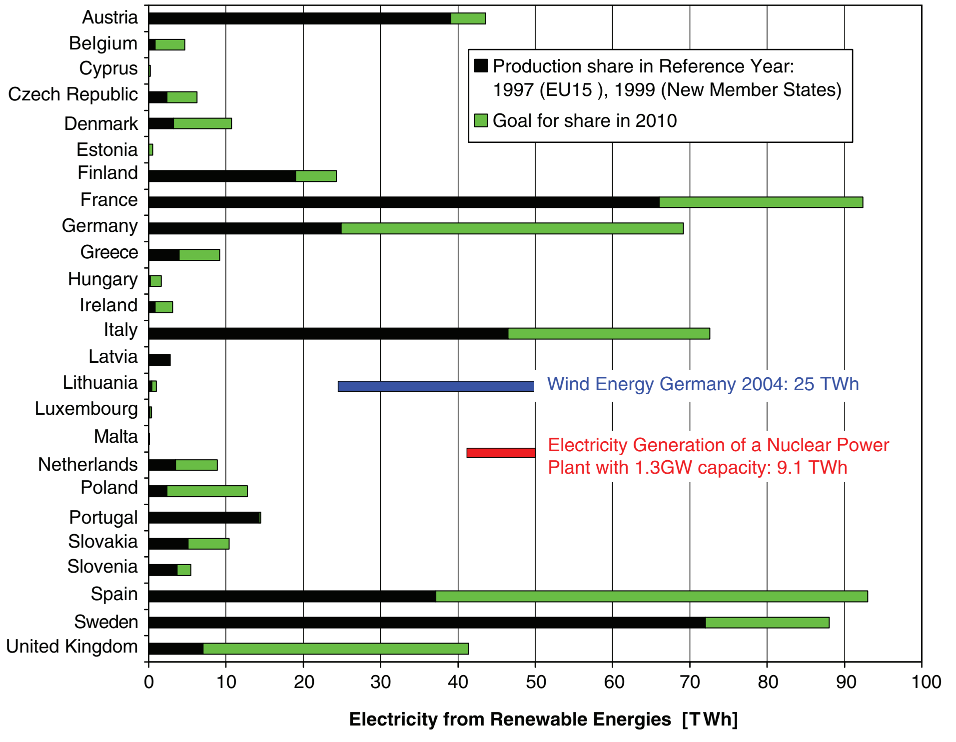


Fig. 2. Indicative Targets for Electricity from Renewable Energies in TWh. The blue bar shows for comparison the electricity generated by a nuclear power plant with 1.3 GW capacity under the assumption of 7000 h annual operation. This corresponds to a 80% availability. The blue bar shows the actual produced electricity by wind in Germany in 2004. Wind turbines have in average 2000 h annual operation.

generation from these PV systems would then be in the order of 2.4–3.5 TWh, depending under which climatic conditions these systems are installed.

However, many Member States are behind in implementing their own targets and thus the overall EU goal. This was shown by a first monitoring communication on this Directive [6]. It revealed the status of non-achievement for some RE technologies, and substantial differences in compliance with the national targets between the Member States. The interpretation was underpinned by a first Commission-staff working document including country profiles [7].

2.2. *Directive on the promotion of the use of biofuels or other renewable fuels for transport (Directive 2003/30/EC) [8]*

Main aspects of the Directive: Member States should ensure that a minimum proportion of biofuels and other renewable fuels is placed on their markets, and, to that effect, shall set national indicative targets. The reference values for these targets shall be 2%, calculated on the basis of energy content, of all petrol and diesel for transport purposes placed on their markets by 31 December 2005 and 5.75%, by 31 December 2010.

Starting 2004 the Member States have to report to the Commission before 1 July about:

- measures taken to promote the use of biofuels or other renewable fuels to replace diesel or petrol for transport purposes,
- national resources allocated to the production of biomass for energy uses other than transport,
- total sales of transport fuel and the share of biofuels, pure or blended, and other renewable fuels placed on the market for the preceding year. Where appropriate, Member States shall report on any exceptional conditions in the supply of crude oil or oil products that have affected the marketing of biofuels and other renewable fuels.

In their first report 2004 the Member States shall indicate the level of their national indicative targets for the first phase, and in 2006 the targets for the second phase. The Commission has to present a first evaluation report for the European Parliament by 31 December 2006 and every 2 yr thereafter. The report should describe the progress made in the use of biofuels and other renewable fuels in the Member States. On the basis of this report, the Commission shall submit, where appropriate, proposals to the European Parliament and to the Council on the adaptation of the system of targets. If the report concludes that the indicative targets are not likely to be achieved, these proposals shall address national targets, including possible mandatory targets, in the appropriate form.

3. Photovoltaics

3.1. The world market

Fig. 3 shows the development of the sale figures from 1990 to 2004. Besides the exponential increase of the world market, which led to a rising interest of institutional investors [9], the booming market in Germany which for the first time overtook the Japanese market in 2004 and the new industry policy for Photovoltaics in the People's Republic of China, was the main news in 2004.

The Photovoltaic world market grew by 58.5% in 2004. Almost half of this growth was due to the exorbitant growth of the German market of more than 235% from 153 MW newly installed solar systems in 2003 to 363 MW in 2004 [11]. The driver for this growth was the new Feed-in Law, which went into effect in 2004 [12]. This development made Germany the biggest market worldwide, surpassing Japan and accounting for 88% of the European market volume. Despite the fact that the European PV production grew by 50% and reached 314 MW, the extreme growth of the German market made Europe after 2 yr of producing roughly the same amount that was installed, a net importer of Photovoltaics again. The ongoing capacity expansions might change this again in the current year.

Between 2001 and 2004 PV installations in the European Union more than tripled to reach 1 GW cumulative installed capacity at the end of 2004. Close to 80% of the total PV installations in the EU were done in Germany. Spain and Austria also doubled their installed PV power, whereas Luxembourg propelled itself to World Champion and leads statistics in terms of installed PV with 58.5 Wp per capita. If the enlarged European Union as a whole were to follow this example, 26.4 GWp installed PV or about 26.4 TWh (0.93% of total EU energy consumption in 2002) per year could be achieved.

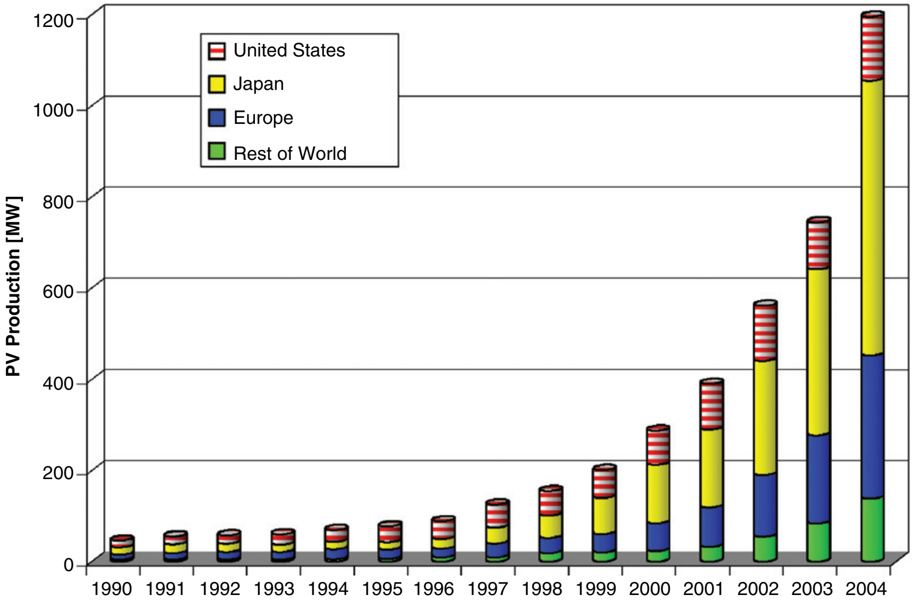


Fig. 3. World PV Cell/Module Production from 1990 to 2004; (data source: PV News [10]).

The second biggest market with 268.8 MW of new installations was Japan with a 25.5% growth rate compared to 2003. About 85% or 238.9 MW of the new installations were grid-connected residential systems bringing the accumulated power of solar systems under Japanese PV residential programme to 834 MW out of 1132 MW total installed PV capacity at the end of FY 2004 [13]. At the same time Japanese exports more than doubled to reach 318.8 MW with more than 224 MW being exported to Europe [14]. Photovoltaic devices manufactured in Japan had a world market share of just over 50% and four of the top 10 companies are Japanese (Fig. 4).

Sharp Corporation continues to dominate the PV scene with more than 27% market share and with the recent increase of production capacity to 400 MW/yr by January 2005 it can be expected that this will not change in 2005 [15]. In addition, it is interesting to note that Sharp finally announced the start of their large-scale thin film production in September 2005 [16]. The 10 largest PV manufacturers together held 79.7% of the market, whereas the rest was shared by over 30 different companies.

The third largest market was the USA with roughly 90 MW of PV installations, with California alone contributing approximately 60 MW in 2004. There is no single market for PV in the United States, but a conglomeration of regional markets and special applications for which PV offers the most cost-effective solution. Until recently, the US PV market was dominated by off-grid applications, such as remote residential power, industrial applications, telecommunications and infrastructure, such as highway and pipeline lighting or buoys. Now the grid-connected market is growing much faster due to a wide range of “buy-down” programmes, sponsored either by States or utilities. In 2004 the ratio was about 55 MW grid connected and 35 MW off-grid.

It is interesting to note that for the first time a Chinese (Taiwan) company MOTECH reached the top 10 list. The People’s Republic of China and Taiwan together produced

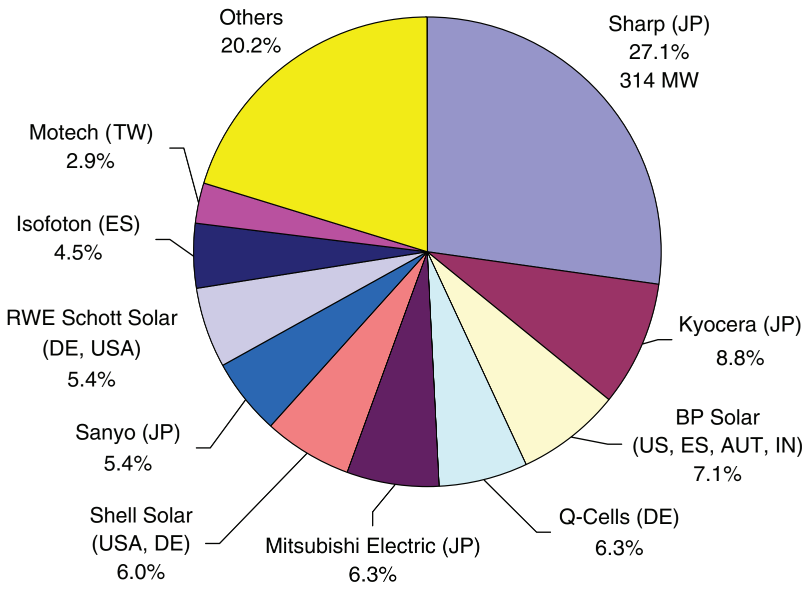


Fig. 4. Top 10 Photovoltaic companies in 2004 (total shipments in 2004: 1195 MW) [10]. Please note that BP Solar, RWE—Schott Solar and Shell Solar have cell production capacities in more than one country.

almost 75 MW, which is already more than half of the US production of 139 MW. The market in the PRC is still quite small, but is expected to grow drastically within the next few years. The goal is to supply 10% of the total primary energy in 2020 by renewable energy. To reach this goal the buildup of a renewable energy and photovoltaics industry is supported by a renewable energy industry policy, as well as a Feed-in Law for electricity from renewable energy.

Fig. 5 shows the announced and estimated increase of production capacities by 2006/07. The figures are taken from press releases [17–21], company websites, public reports [13] or extrapolated from the production increases of the companies during the last years. It has to be noted that the assessment of all the capacity increases is rather difficult as it is affected by the following uncertainties.

The announcements of the increase in production capacity in Europe, the US or China often lack the information about completion date compared to Japan. Due to the Japanese attitude that a public announcement reflects a commitment, the moral pressure to meet a given time target is higher in Japan than elsewhere where delays are more acceptable. In the case of Sharp the prediction is probably too low, taking into account their dominating role in the PV industry. Not all companies announce their capacity increases in advance, so that one can miss out on a major increase if it is well above normal predictions.

Announcements of completion of a capacity increase frequently refer to the installation of the equipment only. It does not mean that the production line is really fully operational. This means, especially with new technologies, that there can be some time delay between installation of the production line and real sales of solar cells. In addition, the production capacities are often announced, taking into account different operation models such as number of shifts, operating hours per year, etc.

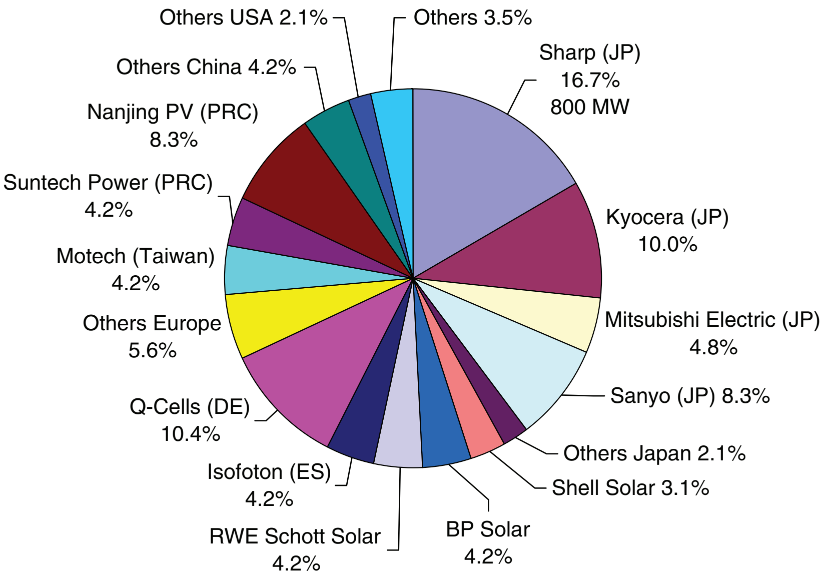


Fig. 5. Announced and estimated increase of production capacities worldwide by 2006/07 (4800 MWp).

Available production capacities are not equal to sales and therefore there is always a noticeable difference between the two figures, which cannot be avoided. The given figure for Sharp is the one most likely to approximate actual production, whereas others might just give the capacity installed in the factory at the end of the year even though it is not yet operational. Despite the fact that only limited comparisons between the different world regions are possible, the planned cell production capacities for 2006/07 portray some very interesting developments.

First of all, should the increases announced be realised, total production capacities will stand at 4800 MW, more than triple the 2004 production figures, which has serious implications on the silicon feedstock demand.

Secondly, compared to last year's announcements 11 companies now have plans to increase their production capacities to 200 MW or more by the end of 2007. Five companies even plan to have 400 MW and more (Sharp, Kyocera, Sanyo, Q-Cells and Nanjing PV) compared to only one company (Sharp) at present. It is very interesting to note that three out of the 11 companies aiming for 200 MW and more are from the People's Republic of China and Taiwan.

This leads to the third observation. If the large increases in production capacity are realised in China, the share on the world market would increase from 5.8% in 2005 to about 22% or 1 GW in 2007. This production capacity would be much more than the 450 MW of solar systems the People's Republic of China announced at the International Conference for Renewable Energies in Bonn [22]. It is obvious that the solar cell manufacturers in China intend to export their production to the growing markets in Europe, the US and developing countries.

Europe is on track to fulfil its own—though not very ambitious—targets for 2010. The introduction of the German Feed-in Law in 1999 and its renewal in 2004 [12], led to

a significant change in the frame conditions for investors and has been one of the major driving forces behind European growth. Since 1999 European PV production has grown on average by 50% per annum and reached about 314 MW in 2004. The European market share rose during the same time from 20% to 26%, whereas the US share decreased due to a weak home market and the Japanese share increased to just over 50%. European PV industry has to continue this growth over the next years in order to maintain that level. This will, however, only be possible if reliable political frame conditions are put in place in the rest of Europe well to enable a return on investment for the PV industry.

Besides this political issue, a continuous improvement of the solar cell and system technology is required. This leads to the search for new developments with respect to material use and consumption, device design, reliability and production technologies as well as new concepts to increase overall efficiency.

Such developments are of particular interest in view of the strategic importance of solar cell production as a key technology in the 21st century, as well as for the electrification of developing countries and the fulfilment of Kyoto Targets.

During the first half of 2004 important events took place, which are already having measurable impact for the photovoltaic market. The European Conference for Renewable Energy "Intelligent Policy Options" organised by the European Commission and held in January 2004 in Berlin adopted the recommendations to the EU institutions to achieve 20% of renewable energy in overall EU consumption by 2020 [23]. The "International Conference for Renewable Energies" in Bonn [22] at the beginning of June and the respective preparatory conferences all around the world, called for an accelerated increase of renewable energies. The follow-up of the Bonn Conference is planned for the 8–9 November 2005 in Beijing. The "2005 Beijing International Renewables Conference" will discuss the status of the global implementation of Renewable Energies. Topics will be the options of a validating and reporting mechanism for the "International Action Plan", which was announced in Bonn, as well as technology transfer. Expected participants will be representatives from all UN Member States as well as international organisations, NGOs and the private sector.

In the Action Plan of this Conference, China announced a 10% renewables target by 2010 and 17% by 2020. The 2010 plan includes the installation of 450 MW photovoltaic systems. However, as already mentioned earlier, the Chinese PV production is expected to grow much faster and Chinese manufacturers will export their products. This trend could again be observed during the 20th European Photovoltaic Solar Energy Conference and Exhibition in Barcelona, 6–10 June 2005. About 22 exhibitors out of 237 came from China, the fourth largest group after Germany, Spain and USA.

The Standing Committee of the National People's Congress of China endorsed the Renewable Energy Law on 28 February 2005. At the same time as the law was passed, the Chinese Government set a target for renewable energy to contribute 10% of the country's gross energy consumption by 2020, a huge increase from the current 1%. The Renewable Energy Law will go into effect on 1 January 2006, but the impact on Photovoltaic installations in China is not clear yet.

In Germany, the revised German Feed-in Law [12] finally went into force on 1 August 2004. The transitional arrangement before and revision itself resulted in a dramatic increase in PV installations. The latest figures of the German Solar Industry Association reported systems with a total of about 360 MW installed in 2004.

Italy and Spain have also passed new Feed-in Laws in 2004. Finally tariffs were officially suggested in Italy in July 2005, but like the Spanish law it has a relatively low cap of 100 MW. Different from the 150 MW cap in Spain, where the law should be revised, the Italian regulation does not foresee such a revision yet. The long-term impacts of these measures are thus still difficult to predict. In the short term, however, the Spanish law has already triggered increased demand and an accelerated market uptake for 2005 is expected.

A growing number of States in the US are emerging as markets where electricity from PV can be considered competitive, with electricity from the grid if different incentives are taken into account. The 2005 Energy Bill, which is expected to increase the demand for Photovoltaics was passed by the Senate on 29 July 2005 and signed by President Bush on 8 August 2005. The Bill's main support mechanisms are:

- increase of the permanent 10% business energy credit for solar to 30% for 2 yr. Eligible technologies include photovoltaics, solar water heaters, concentrating solar power, and solar hybrid lighting. The credit reverts back to the permanent 10% level after 2 yr,
- establish a 30% residential energy credit for solar for 2 yr. For residential systems, the tax credit is capped at $2000.

It is believed that this bill, together with the Californian "Million Roof Initiative" (SB1) and the other initiatives by individual States, will increase the demand for photovoltaic solar systems in the USA by large. However, as administrative hurdles are still not sorted out everywhere, the overall effect still has to be seen.

In June 2004 the Japanese Ministry of Economics, Trade and Industry (METI) announced their "Vision for New Energy Business"—a strategy paper that is aimed at developing an independent and sustainable new energy business explicitly mentioning powerful support measures for PV. Further evidence to develop the PV industry was the June 2005 Symposium on "Photovoltaic Generating Systems" which was entitled "Beginning of the era of GW PV market". During this meeting Ms. Yokiko Araki, Director of the New and Renewable Energy Division of the Agency for Natural Resources and Energy (ANRE) of the Ministry of Economy, Trade and Industry (METI) gave a presentation entitled "Long-Term Energy Supply and Demand Outlook and the Future of PV Power Generation". During this presentation, she announced that one of the mid- to long-term strategies to reduce the dependency an oil was to be the No. 1 PV power nation. This statement can be seen as an announcement for new measures to implement PV in an even lager scale than already today.

These developments have stimulated a plethora of investment decisions all over the world to invest in new solar cell, module and Balance-of-System (BOS) component plants.

3.2. European market

The market conditions for photovoltaics differ substantially from country to country. This is due to different energy policies and public support programmes for renewable energies and especially photovoltaics, as well as the varying grade of liberalisation of domestic electricity markets. Between 2001 and 2004 installations of Photovoltaic systems in the European Union more than tripled to reach 1 GW cumulative installed capacity at the end of 2004. Close to 80% of the total PV installations in the European Union were done in Germany. Spain and Austria also doubled their installed PV power, whereas

Luxembourg propelled itself to World Champion and leads statistics in terms of installed PV with 58.5 Wp per capita. If the enlarged European Union as a whole were to follow this example, 26.4 GWp-installed PV or about 26.4 TWh (0.93% of total EU electricity consumption in 2002) per year would already be achieved (Figs. 6 and 7).

It is of interest to note that almost half of the 2004 worldwide PV market growth of 58.5% was due to the exorbitant growth of the German market of more than 23.5% from 153 MW newly installed solar systems in 2003 to 363 MW in 2004 [11]. The driver for this growth was the new Feed-in Law, which went into effect in 2004 [12]. This development made Germany the biggest market worldwide, surpassing Japan and accounting for 88% of the European market volume. Despite the fact that the European PV production grew by 50% and reached 314 MW, the extreme growth of the German market made Europe after 2 yr of producing roughly the same amount that was installed, a net importer of Photovoltaics again. The ongoing capacity expansions in the order of additional 900 MW by 2006/07 might change this again in the current year.

It is interesting to note that 16 out of 25 Member States have already introduced feed-in tariffs (Table 1). However, the efficiency of this measure to increasingly exploit these countries' PV-potential varies considerably in function of the details in each national regulation. In those states where the tariff does not cover the expenses, its impact is very limited. In some other states, there is a motivating tariff, but its effectiveness is limited due to:

- too early a fulfilled cap.,
- too short a period of validity for the guaranteed increased tariff, or
- administrative requirements being too complicated or even obstructive.

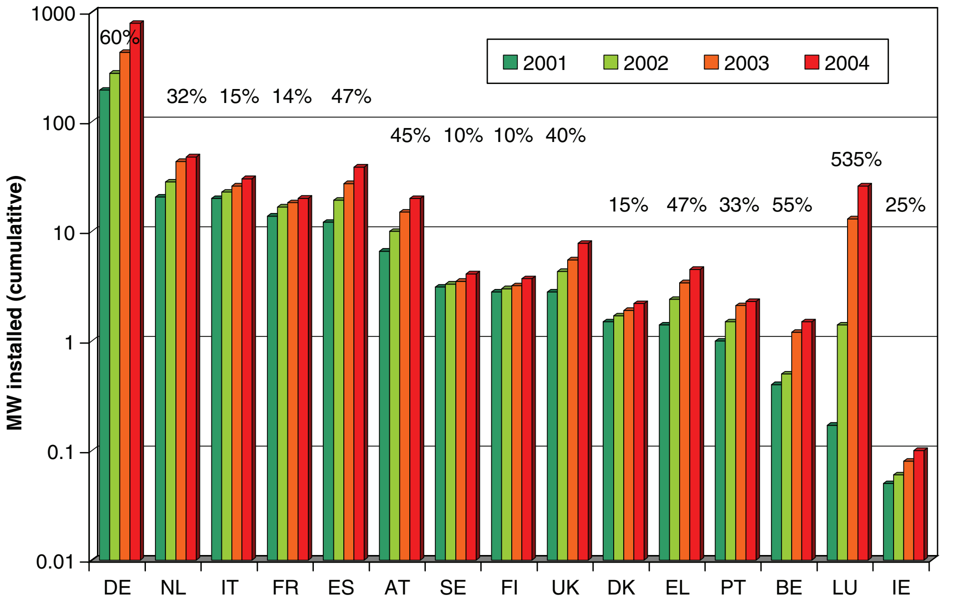


Fig. 6. Cumulative-installed grid-connected PV capacity in EU15 from 2001 to 2004 and average growth rates. Note that capacities do not seem to correlate with solar resources.

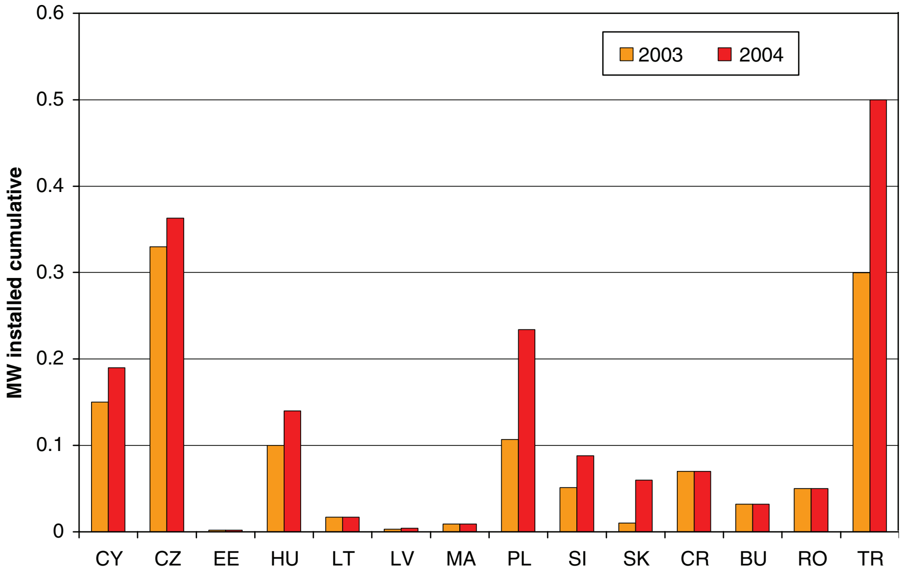


Fig. 7. Cumulative-installed PV capacity in the New Member States and Candidate Countries [11,24–26].

Only in those countries in which the tariff has been high and a set cap. realistic enough have PV installations increased and competition in production and trade developed substantially. From the socio-economic data at hand, feed-in tariffs should be designed to potentially enable a pay-back of the initial investment within 10–12 yr and should be combined with a built-in "sun-set". Such a decrease of the guaranteed tariff by a certain percentage each year, compensates early technology users, enforces realistic price reductions if well designed, and offers a long-term perspective for investors and producers of solar systems.

The New Member States and Candidate Countries still have much lower installation figures (Fig. 7), despite good to very good solar resources, in some states with up to 1600 kWh/kWp (Cyprus, Malta, Romania, Bulgaria, and Southeast Hungary). But even in the Baltic States yearly average values of more than 800 kWh per year are possible for a 1 kWp system, which is comparable to Northern Germany [27].

An important advantage for feed-in tariffs comes to light when analysing the effectiveness with which individuals are motivated—i.e. hundreds and thousands of private (domestic) investors, who have relatively easy access to grid connection, standardised accountability and last but not least, neighbourhood pride—an ideal situation for intrinsically decentralised PV energy. Where local common action (at village or town level) or "locally centralised" investment gives better revenue, the market automatically plays its efficiency-enhancing role. Developments threatening electrical grid stability in terms of demand (e.g., large increase of air conditioning units in the Mediterranean EU) could be compensated much more economically, ecologically and socially balanced by decentralised generation and injection—partly avoiding expensive grid reinforcements. In addition, jobs would be created regionally in installation and maintenance businesses.

Table 1
Support mechanisms for photovoltaic in the European Union and Switzerland (ct = € cent)

Austria	Feed-in tariff paid for 20 years with cap of 15 MWp, but only for systems installed in 2003 and 2004 (cap was reached after only 4 weeks); 0.6 €/kWh < 20 kWp, 0.47 €/kWh > 20 kWp 2005: A new renewable energy law is currently under discussion, but no federal support at the moment. Some of the Federal States have support schemes.
Belgium	Feed-in tariff: 15 ct/kWh; flanders from 1 January 2006: 0.45 ct/kWh (+ 15 ct/kWh with reverse meter; net feed-in) for 20 years with 16.5 MW cap.
Cyprus	Feed-in tariff: 0.12–0.26 €/kWh and investment subsidies up to 55% for private investors and up to 40% for companies.
Czech Republic	New Law on the Promotion of Production of Electricity from Renewable Energy Sources went into effect on 1 August 2005. Producers of electricity can choose from two support schemes: • Fixed feed-in tariffs • Green Bonus Tariffs are not fixed yet, but the ruling states that the tariffs should be set in such a fashion, that the pay-back time of installations is less than 15 years. In addition, the annual price decrease for new installations should be 5% max.
Denmark	No specific PV programme, but settlement price for green electricity.
Estonia	No specific PV programme but Renewable Portfolio Standard and tax relief. Feed-in tariff for electricity produced out of RES is 5.1 ct/kWh.
Finland	Investment subsidy up to 40%.
France	Feed-in tariff mainland: 15 ct/kWh < 12 MW for 20 years; lower VAT on investments. Feed-in tariff Overseas and Corsica: 30.5 ct/kWh.
Germany	Feed-in tariff for 20 years with built-in annual decrease of 5% from 2005 onward. For plants, neither on buildings nor sound barriers, the decrease will rise to 6.5% from 2006 onward. 2005 tariffs: 43.4 ct/kWh minimum; on buildings and sound barriers 54.5 ct/kWh < 30 kWp, 51.9 ct/kWh > 30 kWp and 51.3 ct/kWh > 100 kWp, for façade integration there is an additional bonus of 5 ct/kWh.
Greece	Feed-in tariff: 0.078 €/kWh on islands and 0.07 €/kWh on the mainland. Grants for 40–50% of total cost. Holds only for commercial applications > 5 kW, no grants for domestic applications. Law 2364/95 introduces a reduction of the taxable income of final users installing renewable energy systems in private buildings (75% of costs for purchase and installation is tax-deductible).
Hungary	Ministerial Decree 56/2002: guaranteed feed-in tariff (on indefinite term), beginning in January 2003, all energy generated from renewable energy resources must be purchased between 6 and 6.8 ct/kWh, not technology-specific. Subsidies for renewable energy projects.
Ireland	Alternative Energy Requirement tender scheme (no targets for PV).
Italy	Feed-in tariff: guaranteed for 20 years. The tariffs for 2005 and 2006 are listed below, after that there is a 2% decrease for new systems each year, but tariffs will be corrected according to inflation (ISTAT): (1) up to 20 kW: 44.5 ct/kWh (1 and 2 together have a cap of 60 MW), (2) between 20 and 50 kW: 46 ct/kWh, (3) between 50 kW and 1 MW: 49 ct/kWh (cap of 40 MW).

Table 1 (*continued*)

Latvia	Feed-in tariff: Licensed before 01.06.2001: double the average sales price (~10.1 ct/kWh) for 8 years, then reduction to normal sales price. Licensed after 01.06.2001: Regulator sets the price. A national investment programme for RES has been running since 2002.
Lithuania	Feed-in tariff: 5.6 ct/kWh.
Luxembourg	Feed-in with quota (1% of total energy consumption). < 50 kWp: municipalities 25 ct/kWh and private investors: 45 ct/kWh (after the revision of the law in January 2004); in addition, investment subsidies up to 40% possible (this was also reduced for systems > 10 kWp).
Malta	No specific PV programme yet, but reduced VAT 5% instead of 15%.
Netherlands	Feed-in tariff: 6.8 ct/kWh.
Poland	Tax incentives: no customs duty on PV and reduced VAT (7%) for complete PV systems, but 22% for modules and components. Some soft loans and subsidies. A new law was passed in April 2004 that tariffs for all renewable energies have to be approved by the regulator (until now only for projects larger than 5 MW).
Portugal	Feed-in tariff: 41 ct/kWh < 5 kWp and 0.224 ct/kWh > 5 kWp. In addition investment subsidies and tax deductions are available.
Slovakia	Feed-in tariff st by regulator each year: 8 SKK/kWh (ca. 26 ct/kWh) for 2006. Tax deduction on income earned. RES feed-in tariff in 2005: ~3 ct/kWh.
Slovenia[a]	Feed-in tariff: either fixed price or electricity price (8 SIT/kWh) + premium. Uniform annual price: 37.4 ct/kWh < 36 kWp and 6.4 ct/kWh > 36 kWp. Uniform annual premium: 34.0 ct/kWh < 36 kWp and 3.1 ct/kWh > 36 kWp.
Spain	Feed-in tariff with cap of 150 MW: 0.396 €/kWh < 100 kWp for 20 years (previously limited to 5 kWp systems), with payment on 80% of rated power output beyond that; > 100 kWp 0.216 €/kWh.
Sweden	70% tax deduction on investment and installation cost for systems on public buildings proposed as from beginning of 2005 and for 36 months onwards. Electricity certificates for wind, solar, biomass, geothermal and small hydro. Energy tax exemption.
Switzerland	Net metering with feed-in tariff of min. 0.15 CHF/kWh (10 ct/kWh); investment subsidies in some cantons; promotion of voluntary measures (solar stock exchanges, green power marketing).
United Kingdom	Investment subsidies in the framework of a PV demonstration programme. Reduced VAT.

[a] 1 °€~240 °SIT.

Stable political and socio-economically viable frame conditions do not only convince private and commercial investors to install photovoltaic power plants, but also stimulate the investment in new production capacities for solar cells and modules. Especially in Germany and Spain, the most dynamic markets in Europe, the production capacities for solar cells and modules have increased faster than in the other European countries (Fig. 8).

Since the introduction of the Feed-in Law in Germany, employment in the renewable energy sector has more than doubled compared to 1998. The latest figures given by the

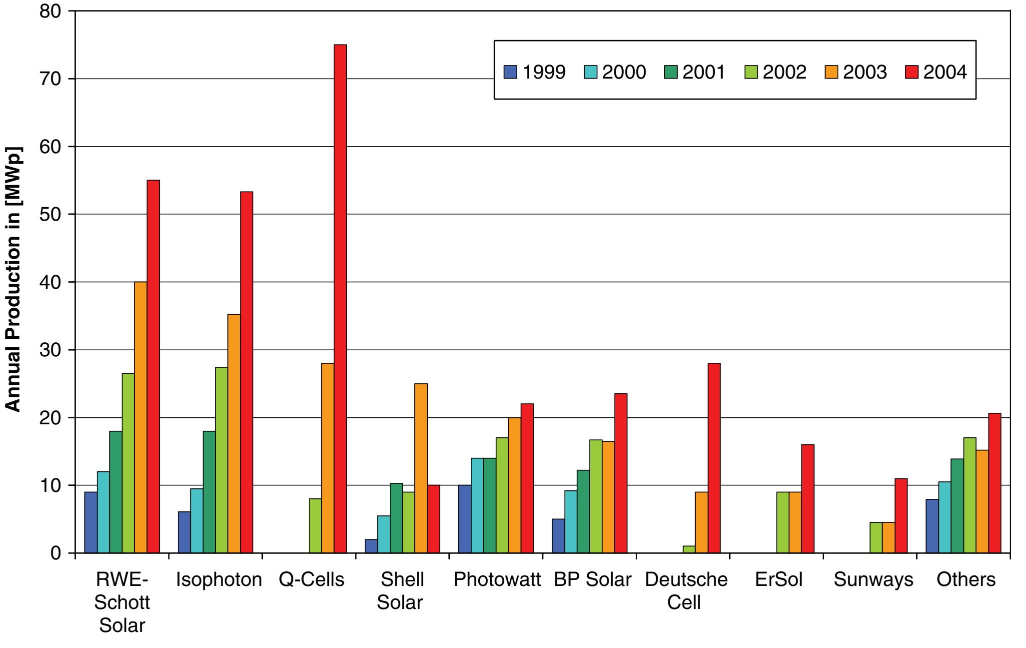


Fig. 8. Annual production of the European PV manufacturers with sales larger than 10 MWp in 2004 [10].

German Renewable Energy Association (BEE) in June 2005 count more than 140,000 people employed in this sector (including Services and R&D) with approximately 20,000 in Photovoltaics [28]. According to an industry survey amongst renewable energy companies in Germany, every second company plans to increase the number of employees by 30–100% within the next 5 yr. Photovoltaic companies are amongst the most optimistic ones and in total expect a doubling of employment by 2010. In 2004 Photovoltaics accounted for a turnover in Germany of € 1.5 billion and 70% of the added value remained inside Germany.

It is interesting to note that since 1999, the majority of investments in solar cell production facilities in Europe were made in Germany and Spain—the two countries that offer the most stable and realistic legal framework conditions for citizens investing in a PV system. For the whole of Europe, one can estimate current employment figures in Photovoltaics in the range 25,000–27,000.

The continuous expansion of the production capacities for solar cells is of particular importance in light of the export markets for solar systems to the rural areas in Asia, Africa and South America, where about 2 billion people are still without electricity. The Europeans should not lose this future market, also with respect to the possibility it offers for the labour market. In June 2004 the European Photovoltaic Industry Association (EPIA) published its recent photovoltaics roadmap and stated therein: "Failure to act on the recommendations of this Roadmap will be a huge missed opportunity. Europe will suffer the loss of its current strong market position and potential major industry for the future. The PV industry can be of great importance to Europe in terms of wealth and employment, with 59,000 PV related jobs in the EU in 2010 if the targets are met, and a figure of 100,000 jobs would be realistic if export opportunities are exploited".

According to EPIA, new PV production facilities create about 20 jobs per MW of capacity adding about 30 additional jobs per MW-installed capacity in the wholesale, retail, installation and maintenance services sector. The later jobs are mostly located on a regional level near to the final customer. The goals set by EPIA in its roadmap are cumulative installed photovoltaic systems with 3.6 GWp electricity generation capacity in Europe by 2010 and the respective job numbers mentioned above would correspond to roughly 1.2 GW per year production capacity of cells and systems in the first case and roughly double in the export case. These figures look quite realistic if the planned expansions of production capacities in the order of 900 MW for 2006/07 in Europe are added to the realised production of 314 MW in 2004.

A prerequisite for all such developments is that parallel to the public market introduction incentives, electricity generated by solar systems can be *freely traded and attain preferential grid access.* As PV systems contribute to the avoidance of climatically harmful greenhouse gases, it has to be ensured that electricity generated from solar systems be exempt from eco taxes where applicable. In addition, one has to enable PV system operators to sell green certificates to CO_2-producers.

The European Union is on track to fulfil its own target of 3 GWp in terms of *Renewable Electricity from Photovoltaics* for 2010. Compared to Japan, which seeks to achieve 4.8 GWp (approx. 38 Wp per capita), however, this is not very ambitious. If the growth rates realised in the installation of PV systems between 2001 and 2004 could be maintained in the next years, the White Paper target would already be achieved in 2007 (Fig. 9).

In 2010, total installations would then exceed 10 GWp or approx. 22 Wp per capita, which would still be less than the Japanese target of 38 Wp per capita. The adoption of the Japanese target would result in 17.25 GWp installed in 2010, which would generate around 17.25 TWh or 0.61% of total EU electricity consumption in 2002. The PV installation growth rate curve in the European Union exactly mirrors that of wind power, with a delay of approximately 12 yr.

The introduction of the German Feed-in Law in 1999, with its revision in 2004 and a number of countries following up on this trend, led to a significant improvement in the frame conditions for investors. Since then, European PV production grew on average by 50% per annum and reached over 310 MW in 2004 [10]. Despite this impressive production growth, the even faster growth of PV system installations, especially in Germany, led to the situation that Europe was just able to produce as many solar cells as PV systems were installed in 2003, but became a net importer again in 2004. European world market share increased in the same time from 20% to over 26%, whereas the US share decreased due to a weak home market. In consequence the Japanese share also increased to 50%.

The European PV industry has to continue its impressive growth over the next years in order to maintain its market position. This will only be achieved if reliable political framework conditions are created and maintained to enable return on investment for PV investors and the industry alike. Besides this political issue, targeted improvements of the solar cell and system technology are still required.

The recently passed feed-in tariffs in Italy and the introduction of Feed-in Laws in a growing number of countries in the European Union are encouraging signs. The proposed draft for the Greek PV feed-in tariffs is another promising development. Different tariffs for the mainland and the islands ranging between 15 ct/kWh for large systems exceeding 2 MWp up to 57 ct/kWh for systems smaller than 200 kWp are proposed. These

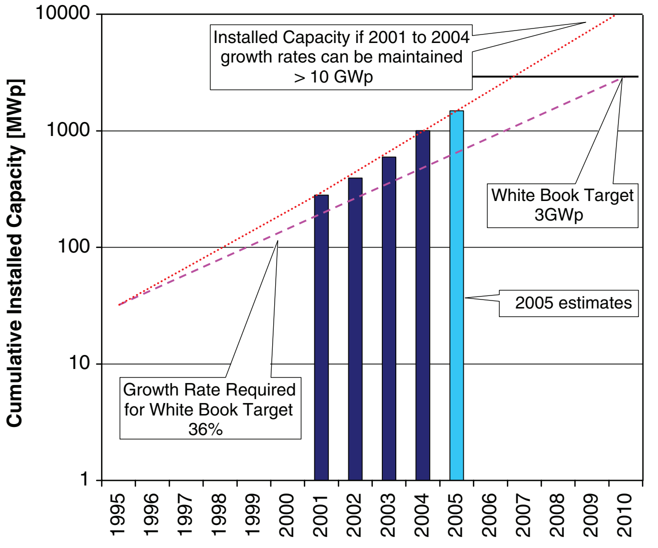


Fig. 9. White Paper target growth rate and estimates based on 2001–04 installations.

developments give rise to the hope that over the next years, these markets will grow as dynamically as the German one, thus leading the way to a Europewide PV boom.

3.3. PV research in Europe

In addition to the 25 national programmes for market implementation, research and development, the European Union has been funding research (DG RTD) and demonstration projects (DG TREN) with the Research Framework Programmes since 1980. Compared to the combined national budgets, the EU budget is rather small, but it plays an important role in creating a European Photovoltaic Research Area. This is of particular interest and importance, as the European PV industry is much more fragmented than competitors in the US and Japan (Fig. 10). A large number of research institutions from small University groups to large research centres covering everything from basic material research to industry process optimisation are involved and contribute to the progress of photovoltaics. In the following only activities on the European level will be listed, as the national or regional activities are too manifold to be covered in such a report.

The European Commission's Research and Development activities are organised in multi-annual Framework Programmes (FP), with a duration of 4 yr. Support for photovoltaic research projects started in 1980. In FP4 (1994–98) 85 projects were supported with a budget of € 84 million. During the next Framework Programme FP5 (1998–2002) the budget was increased to around € 120 million and the budget was divided into research projects and demonstration projects. In the demonstration part, around 40 projects were supported with € 54 million and within the research budget 62 projects were funded with € 66 million. The research projects were classified in five different categories listed below:

- European Research Area: 6 projects;
- Materials Cells and modules: 34 projects;

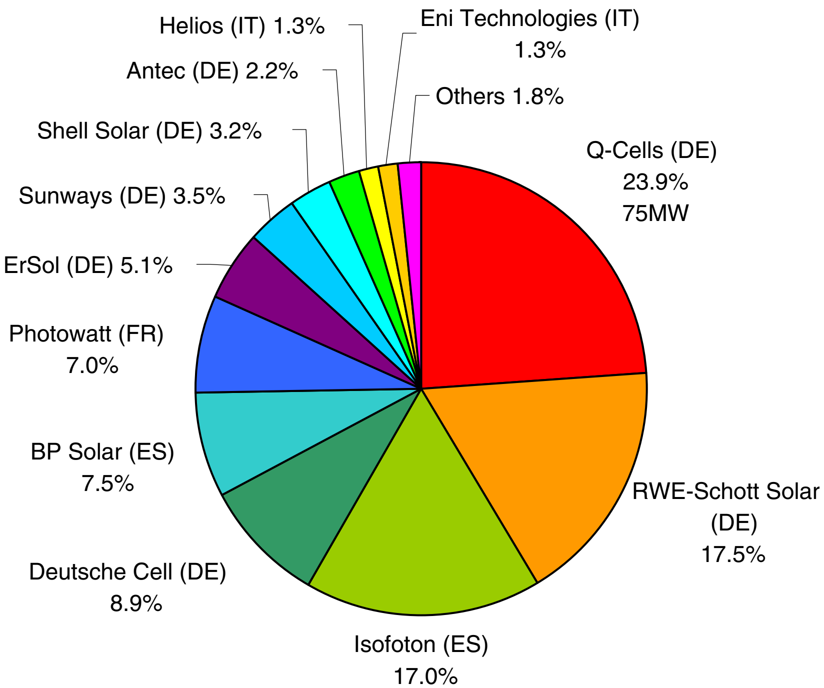


Fig. 10. Shares of the European PV companies in European production (2004: 314 MW, this corresponds to 26.3% of the worldwide sales) [10].

- Systems: 10 projects;
- Building integrated photovoltaics: 7 projects;
- Standards and others: 5 projects.

The European Commission introduced new funding instruments for the 6th Framework Programme (FP6) from 2002 to 2006. The first, called "Integrated Projects" (IPs), is designed to create the knowledge required to implement the priority thematic areas of FP6, by integrating a critical mass of activities (research, demonstration, training, innovation, management) and resources (staff, skills, competence, finances, infrastructure, equipment, etc.). The second, called Networks of Excellence (NoE), is an instrument for the direct tackling of the fragmentation of research activities in Europe in a given thematic area.

In addition, a third instrument, known as "Article 169", a reference to the treaty establishing the FPs, is new in the sense that it will be used for the first time. This Article 169 instrument allows the Commission to support the opening and joining of national research programmes of Member States.

The "shared-cost research projects" of earlier FPs are now represented by "Specific Targeted Research Projects" (STREP), improving existing or developing new products, processes or services or contributing to meet the needs of society or Community policies. These STREPs will have some differences in contractual areas and IPR rules.

Concerted actions and thematic networks have been replaced by "Co-ordination Actions" which are essentially additional actions intended to promote and support the networking and co-ordination of research and innovation activities.

The "Accompanying Measures" of FP5 have been replaced by "Specific Support Actions", which are actions the Commission may wish to take in support of the Framework Programme. They can comprise needs studies, input to policy, showcasing research results, seminars, groups, etc.

For the current 6th Framework Programme (2002–2006) € 810 million are foreseen for the topic "Sustainable Energy Systems", split into two equal parts for "short to medium" and "medium to long" term research, which includes PV. However, no specific budget was earmarked, especially for PV. The first call was published on 17 December 2002 and the successful projects of the 2002 and 2003, listed below, started in 2003 and 2004. Until now € 8.2 million have been awarded to three "short to medium" projects and € 33.6 million to six "medium to long term" projects. Together this amounts to a share of roughly 10.3% of the "Sustainable Energy Systems" budget for photovoltaics.

Short- to medium-term projects:

- *Integrated Project*
  - PV-MIPS: Photovoltaic module with integrated power conversion and interconnection system.
    EU funding: € 4.4 million—Co-ordinator: ISET-Kassel
- *STREPs*
  - SOLAR PLOTS: Multiple-ownership grid-connected PV with optimised tracking and low concentration reflectors.
    EU funding: € 1.8 million—Co-ordinator: Alternativas Energéticas Solares, Tafalla.
  - BITHINK: Bi-facial thin industrial multi-crystalline Silicon Solar cells.
    EU funding: € 2 million—Co-ordinator: CENER-CIEMAT, Madrid.

Medium- to long-term projects:

- *Integrated Projects*
  - CRYSTAL CLEAR: Development of Crystalline Silicon PV technologies for low-cost high-efficiency and reliable modules.
    EU funding: € 16 million—Co-ordinator: ECN, Petten.
  - FULL SPECTRUM: Development of new concepts for third-generation PV materials and techniques aiming at very high efficiency solar cells.
    EU funding: € 8.4 million—Co-ordinator: IES-Madrid.
- *STREPs*
  - HICONPV: High concentration PV system.
    EU funding € 2.7 million—Co-ordinator: SOLUCAR Energia, Sevilla.
- BIPV-CIS: Improved integrated PV using thin-film CIS modules for building retrofit (this project was merged).
  EU funding: € 2.3 million—Co-ordinator: ZSW, Stuttgart.
- MOLICELL: Molecular materials and hybrid nano-crystalline/organic solar cells (this project was merged).
  EU funding: € 2.5 million—Co-ordinator: CEA-GENEC, Cadarache.
- *Co-ordination Action*
  - PV-CATAPULT: Long-term research, technology, market and socio-economic aspects for the PV sector; PV-Thermal Forum; European Photovoltaic Performance Initiative Collaboration (this project was merged).
    EU funding: € 1.7 million—Co-ordinator: ECN, Petten.

The second major call for projects closed in December 2004. Five proposals were selected, but the contract negotiations for these projects are still ongoing.

- ATHLET (IP) on advanced techniques for low-cost thin-film cells and modules.
- PERFORMANCE (IP) on pre-normative actions focusing on performance assessment, including BIPV codes.
- LARCIS (STREP) on large-area CIS module for MW-scale production.
- FOXY (STREP) on solar-grade silicon feedstock, wafers and cells.
- FLEXCELLENCE (STREP) on industrial manufacturing of thin-film silicon PV modules using low-ost roll-to-roll technology.

In addition to these technology-oriented research projects, there are two more projects dealing with Photovoltaics in a political context. The first one is an ERA-NET. The objective of the ERA-NET scheme is to step up the co-operation and co-ordination of research activities carried out at national or regional level in the Member States and Associated States through:

- the networking of research activities conducted at national or regional level, and
- the mutual opening of national and regional research programmes.

The scheme will contribute to making a reality of the European Research Area by improving the coherence and coordination across Europe of such research programmes. The scheme will also enable national systems to take on tasks collectively that they would not have been able to tackle independently.

- *PV-ERA-NET*

Objective: Networking and Integration of National and Regional Programmes in the Field of PV Solar Energy Research and Technological Development (RTD) in the European Research Area (ERA).

Project Funding: € 2.57 million, Coordinator Forschungszentrum Jülich GmbH; Project Management Group "Energy–Technology–Sustainability" (PT-ETN).

The second project is funded through the "Intelligent Energy—Europe" (EIE) Programme. This is the Community's support programme for non-technological actions in the field of energy efficiency and renewable energy sources. The programme was adopted in June 2003 and its duration is from 2003 to 2006.

EIE supports the European Union's policies in the field of energy as laid down in the Green Paper on Security of Energy Supply, the White Paper on Transport and other related Community legislation (including the Directives on renewable electricity, energy performance of buildings and biofuels). Its aim is to support sustainable development in the energy context, making a balanced contribution to achieving the general objectives of security of energy supply, competitiveness, and environmental protection.

- *PV Policy Group*

This project aims at overcoming political–legal barriers that are currently preventing investments in the majority of European PV markets. About eight national energy agencies

of the key "solar nations" (DE, FR, NL, AUT, SLO, POR, GR, ES) will form a "PV Policy Core Group" to define common actions for the improvement and alignment of national support systems for PV. Coordinator: German Energy Agency (DENA), Berlin; EU-Funding € 541.448 (50%).

The European Commission is currently preparing the third call for proposals under EIE. The call is likely to be published towards the end of September this year and it will be open until early 2006.

4. Conclusion

For Photovoltaics (PV) Europe is on track to fulfil its own—though not very ambitious—targets for 2010. The European market is still dominated by Germany, where the introduction of the Feed-in Law in 1999, led to a significant change in the frame conditions for investors. Since then European PV production grew in average by 50% per annum and has reached 315 MW in 2004. European market share rose in the same time from 20% to 26%, whereas the US share decreased due to a weak home market and the Japanese share increased to around 50%. European PV industry has to continue this growth over the next years in order to maintain this level (Fig. 11).

Besides the political issues a continuous improvement of the solar cell and system technology is required. The research programmes in Europe, Japan and the US all fund new developments with respect to material use and consumption, device design, reliability and production technologies as well as new concepts to increase the overall efficiency. However, the main difference is the focus on production issues, which is strongest in Japan followed by the US and Europe. The new initiative of the PV Technology Platform in Europe could make a change to strengthen research and technology transfer as well as organise a better coordination of resources, which is needed in Europe in order not to lose the technology race.

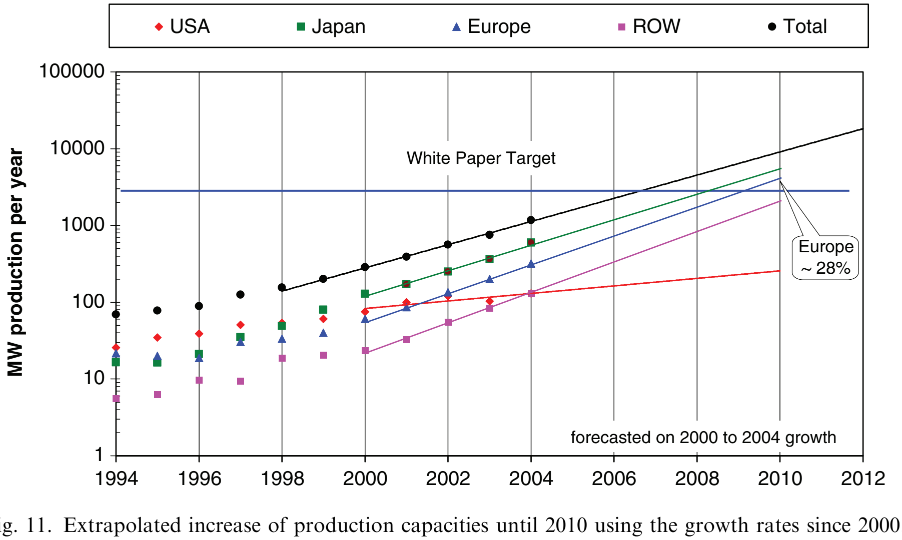


Fig. 11. Extrapolated increase of production capacities until 2010 using the growth rates since 2000.

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